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# Green chemistry: attempts to save our environment

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## ABSTRACT

Realizing the need for protection of the environment, scientists introduced Green Chemistry as a new branch of Chemistry. It aims to minimize the production of hazardous wastes, reduce the cost of chemicals, protect the environment and the humans from various types of chemical-induced risks, and to monitor the environment-conservation mechanisms. This review article aims to discuss about how the principles of Green Chemistry help in reduction of risks due to chemicals, terrorism control, sustainable development by proper utilization of resources and creation of a better world overall. Attempts have been made to include some efforts made

internationally to promote this branch of Chemistry, inspire the researches and students to dedicate themselves in the field and motivate the industries to practise Green Processes for sustainable development.

Keywords: green: chemistry – risk: reduction – promotion – sustainable: development

## 1. INTRODUCTION

Most of the easy fixes have already been adopted in the industries as well as industrialized areas to reduce pollution. It is due to this reason that now, even a small improvement requires huge amount of money and resources that have made further environment conservation a challenging task. For the same reason, the idea of green chemistry was introduced. This term was introduced by chemist Paul T. Anastas in 1991. [2] Green Chemistry involves practices that are environment friendly, safe, sustainable, produce negligible amount of waste and minimize the energy usage while boosting the pollution-control mechanism. [1] The idea behind Green Chemistry is that incorrect production of chemicals in the large scale, their inappropriate processing, unsustainable usage and unplanned disposal can lead to several environmental hazards. Thus, one of the major principles of Green Chemistry is to collaborate with Green Chemical Engineering to produce chemicals and design mechanisms that produce almost no waste at all. Moreover, Green Chemistry focuses on creating awareness that unwise use of chemicals can cause environmental pollutions- thus warning the chemical-producing industries to be effective in terms of producing environment-friendly chemicals.

Green Chemistry is in fact one of the newest fields of Chemistry and has much more yet to be discovered. However, many ideas of Chemistry that have been developed much earlier than the birth of Green Chemistry are effectively used in it, which is one of its beneficial features. One of such ideas is production of chemicals by the use of knowledge of Chemistry researches and utilizing them to produce non-toxic and disposable chemicals which do no or very little harm to the environment. Moreover, Green Chemistry seems to be related to Economics as in the sense that it favors the economic theories of maximum output with minimum investment.

### *The Twelve Principles of Green Chemistry*

12 principles of Green Chemistry were given by Paul Anastas and John C. Warner to form the basic concepts for the subject. [4] The principles are:

**1. Prevention:** Cleaning or treating the waste and trying to minimize the effects of pollution is good but it is better to prevent such hazards on the first place. This is the key principle upon which Green Chemistry stands. Before the introduction of Green Chemistry, scientists rarely focused on production of waste-free and non-toxic products and were more concerned on the control of hazards. However, Green Chemistry revolutionized the way chemists think and redirected their focus on "Prevention is better than cure."

**2. Maximization of Synthetic Methods:** Most synthetic methods result in at least 10% waste and their best yields are somewhere between 70 to 90%. However, Green Chemistry focuses to revolutionize the synthesizing methods by ensuring all the reagents are effectively converted into final product without leaving any waste materials and reducing the need to recycle and reuse. This is called the concept of "Atom Economy" and was developed by Barry Trost. [2]

**3. Chemical synthesis in a less hazardous manner:** Green Chemistry focuses to promote the usage of less toxic ingredients in the manufacture of various synthetic products. This reduces the hazards that the working staffs in the industries as well as the researchers in the laboratories face and also plays a significant role to reduce environmental pollution. The efforts of Green Chemistry has resulted in polymer synthesis being redesigned to stop the usage of very toxic organic solvents and reagents. [22]

**4. Design of Safe Chemicals:** Green chemists promote the designing of such chemicals which have minimum effect on the human health and the surrounding environment. Out of the 100,000 chemical materials available in the market, majority are toxic in nature and yet, they are not properly monitored. [2] Green Chemistry focuses on the monitoring of such toxic products to ultimately promote the design of safer chemicals. Thus, less persistent and more selective pesticides have been promoted these days to replace the harmful pesticides.[19] Polymers have been designed in such a way that they get deteriorated at the end of their lifetime, without causing much harms on the environment. [20]

**5. Auxiliary substances and safer solvents:** In the process of chemical synthesis, various solvents, separation agents and auxiliary chemicals are used which are toxic in nature. These must be replaced by non-toxic substances or at least be reduced in use. Green



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Chemistry ensures that less toxic solvents are used in the manufacture processes and alternative methods are promoted for better yield with less toxicity. The use of $CO_2$ as a solvent is gaining popularity these days because of its non-toxic, and nonflammable property, and also because its critical temperature and pressure (T=31.1°C and P=74 bar) are much more easy to achieve compared to that of solvents like water(T=374°C and P=221 bar).[12]-[15] So, supercritical $CO_2$ is often used as a replacement to perchloroethylene in dry cleaning industries in the form of solvent and also in the manufacture of semi-conductors to avoid the hazards caused by water during the conventional and chemical processing. [16]-[18]

**6. Energy-efficient Design:** Previously, chemists rarely focused on energy requirements during the synthesis of various chemicals. However, Green Chemistry promotes development of better methods in terms of efficiency and to conduct various manufacture processes at room temperature and normal atmospheric pressure to lessen the requirements of energy.

**7. Promote the Use of Renewable Raw Materials and Feedstocks:** According to the principle of Green Chemistry, the various types of raw materials involved in chemical synthesis should be less toxic and renewable as far as possible. About 98% of the organic chemicals are obtained from petroleum products which is why Green Chemistry aims to discourage the use of petroleum products. [21]

**8. Reduction of Intermediate Derivatives:** During the synthesis of desired products, the unnecessary routes and derivatization should be reduced, according to Green chemists. Otherwise, unnecessary amount of reagents should be used and wastes are produced in large amount which is against the environment conservation strategies. Thus, this principle motivates the chemists to look for new, short and effective reactions to produce synthetic products that can replace the old, long and inefficient chemical processes.

**9. Catalysis and catalytic reagents:** Catalysts are those substances that change the rate of reaction. Catalysts can have drastic impacts not only on the efficiency of reactions but also in the yield of quality products. They often lessen the energy requirements which make the processes environment-friendly. [7]-[10] It is due to this reason that catalysis is time and again referred to as the "foundation pillar" of Green Chemistry. [6] One of the remarkable applications of this principle of Green Chemistry was the Nobel Prize-winning contribution of Sharpless, Noyori, and Knowles to produce single enantiomer compounds, especially for pharmaceutical industries. [11]

**10. Design of easily degradable products:** Often, chemical products are non-degradable or take a very long time to degrade. This causes several environmental hazards. It is due to this reason that Green Chemistry promotes the manufacture of such products which can break down into simpler form easily when acted upon by the decomposers.

**11. Real-Time Analysis to Prevent Pollution:** The monitoring mechanism for checking environmental pollution aren't effective-enough due to lack of real-time analysis. Thus, Green Chemistry promotes the mechanisms that all real-time control mechanism to monitor the hazardous processes and help to effectively implement the environment-conservation laws.

**12. Safer Chemistry for Prevention of Accidents**: Various chemicals and raw materials that are utilized during the synthesis of various products should be inherently safe and their properties should be non-toxic. Moreover, their product after degradation should also be non-toxic and should not cause any hazard to human health and the environment. Green Chemistry focuses on stopping the use of hazardous chemicals for better health of not only the workers in the industries but also for the consumers.

Even though all these principles haven't been perfectly applied, progress has been made in their implementation. Availability of various non-toxic products in the market, creative innovations leading to various bio-degradable chemicals, the increasing awareness on the use of renewable sources of energy, the industrial policies of using less-hazardous chemicals in the synthetic processes and the improvements in the monitoring of pollution are indications of the effectiveness of the principles of Green Chemistry.

## 1.1. Reduction of Risk to Human Health and the Environment

$$RISK = f(Hazard \times Exposure)$$

The amount of risk involved in the use of any chemical product is a function of hazard and time of exposure.[1] So, hazardous substances can be risky even if the exposure time is less. Moreover, it also means that even the exposure to less hazardous substances for a long period of time results in high risks. This is why the toxic chemical products which aren't very hazardous on the short term, can prove to be serious risk factors on the long term. This can ultimately degrade the environment as well as the health of humans and the worst part is that people often don't even realize such long-term effects.



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Even though risks can be minimized by reducing the exposure time, constant safety measures have to be adopted in the laboratories where the synthetic work is carried out which requires constant nagging of personnel just like a laboratory instructor nags his students to wear laboratory coat and safety goggles at all time. Moreover, visitors that walk bare-face to the laboratory may be susceptible to various sorts of eye-problems, provided that they ignore the warnings for eye-damage. They may be exposed to the smell of various types of harmful chemicals if they don't follow the instructions carefully. In addition, their skin may be exposed to various types of radiations that might be used in the laboratory for the synthesis of different chemicals, provided that they don't use certain type of expensive radiation-protecting suits.

In fact, the precaution measures to reduce the exposure to hazardous chemicals for minimizing risk factors are not only hard to adopt but also often high in costs. In contrast, reduction of hazardous chemicals is often a much cost-effective procedure. Since this results in reduction of the precaution measures to prevent exposure, the overall cost in reduced by a great amount.

Therefore, Green Chemistry focuses on the minimization and prevention of risk factors by controlling the production of hazardous substances and by using safer methods of synthesis. This is why Green Chemistry promotes the production of less hazardous products and has the aim to ultimately produce non-toxic and non-hazardous products. Production of completely non-hazardous chemicals is hard but the minimization of hazards is much easier and has thus been achieved effectively in the last 20 years. This has resulted in the reduction of various types of risks to the human health as well as the environment.

### 1.2. Risk Reduction Limit

Even though attempts should be made to reduce risks, there is a certain limit beyond which the efforts made to reduce risks become counterproductive and affect other areas.[1] An example of huge Boeing can be considered for illustration. The aircraft has hundreds of passengers, more than 50 tons of aluminum, steel and flammable fuel and yet, it travels at speed almost thrice the legal speed for automobiles. When such aircraft comes across even small cracks or fragile on the concrete, disastrous event with loss of hundreds of life and millions of dollars is the result. Even though such high risks are involved, thousands of flights are carried out every single day and the rate of such disaster is not even a few percent. It is because different strategies are adopted to minimize the hazards. It includes rechecking of the engines, skilled pilots, regular maintenance of the concrete of airport and much more, which makes the flight effective in terms of safety. In fact, the complete reduction of such risks would require flights to be completely stopped which definitely proves to be counterproductive as it increases risks in other aspects of economy. Thus, a certain limit of calculated risk is involved in such flights.

Here's another example to clarify the concept. A businessman must be willing to take certain amount of risks. Otherwise, he will be too timid to invest in any aspect of his business. The desire to avoid all the risk factor can lead to complete failure in his business. Therefore, he makes sure he is courageous enough to take certain amount of risk. However, he doesn't want to take the risk without some effective safety strategies. So, he adopts various insurance policies which will support him if his investment turns out to cause massive loss. In this way, strategies to minimize the hazard can be much effective in certain cases rather than avoiding the risk completely.

Similarly, certain limits of risks are involved in the synthesis process. Attempts to absolutely reduce the risks will only prove to be futile in the longer run. Thus, Green Chemistry aims to target a specific degree of risk reduction and beyond that, it focuses to adopt cost-effective strategies to reduce exposure and the hazard in the chemicals.

## 2. GREEN CHEMISTRY FOR A SUSTAINABLE PROSPERITY AND A MUCHSAFER WORLD

Green Chemistry focuses to create a much safer world through terrorism control. By production of non-toxic and non-hazardous chemicals, it ensures that the products cannot be diverted in use to make terrorist attacks on large quantities. Moreover, chemicals are designed effectively to perform only specific functions so that the chances of them being misused to create terror are significantly reduced.. Products that can result in violent reactions and fire are strictly reduced. The processes that are governed by the principles of Green Chemistry are carried out in low temperature and mild conditions that significantly reduce the energy consumption. As a result, these processes don't have to rely on uncertain sources for energy which might sometimes be run by terrorists. This prevents the possible blackmails and disruption in business.[1]. Thus, industries focus on implementation of Green Chemistry to reduce various risk factors, hazards and vulnerabilities for attack. Moreover, the leading petroleum producers are the grounds for different terrorist activities, in the present context. Creating independence to such countries requires proper utilization of the renewable energy sources in abundance so that terrorist threats are significantly reduced. Since Green Chemistry focuses on



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promotion of renewable sources of energy, terrorism control can be much effective and the people can feel much safer than ever before

Often, people under poverty and hopeless conditions get involved in creating terror in the societies by getting involved in gangs and threatening for money. Since they hardly get their primary needs of food, shelter and clothes fulfilled, they are desperate for money. This encourages them to look for ways to get money- the easiest one being robbery and criminal activities. However, poverty reduction can lead to a safer society where violent acts are less common. As Green Chemical Practices lead to certain degree of fulfillment of human needs and improve the living standard of many people, the society can be much prosperous and thus safer from different types of violent activities.

Mostly, temporary prosperity is the result of consumption of the scarce natural resources and the destruction of the environment. However, Elsa Reichmanis has correctly highlighted the drawback of such prosperity- "We are past the days when we can trade environmental contamination for economic prosperity; that is only a temporary bargain, and the cost of pollution both economically and on human health is too high."[3]However, practices based on the principles of Green Chemistry can improve the quality of life of people without exploiting the environment. These practices include sources of abundant energy that can be used in a sustainable manner without high cost and hazards in the nature.

The sustainable, readily available, safe and eco-friendly energy can be used to light bulbs, cook food and carry out various household activities in a cost-effective way. Moreover, water can be heated easily and with less cost during the winter time to have a hot-bath which can prevent people from various types of diseases caused by exposure to cold weather. In addition to that, various types of energy can be used to purify the water sources which will result in healthy people in the society. This means less misery and the ability of people to get involved in various activities increases. Moreover, such energy can be used in supplying water to the farm and increase production in the farm. More production means more profit after sale and a better quality of life of the farmers. This reduces frustration among such people. As a result, they become capable to participate in different income-generating activities and this creates ripple of many positive changes in their life- resulting in sustainable prosperity.

In this way, sustainable supply of eco-friendly energy can cause drastic changes in people's life and such supply isn't possible without the application of Green Chemistry and Green Engineering. Renewable sources of energy like solar and wind energy can be used for such purpose, however, their storage in large amount and transportation is a problem. For instance, the wind-powered generators are usually far from the city areas where the energy is required. Similarly, solar plants are much effective in remote desert locations. However, if superconductor or quantum conductors are used as ways of transporting energy, the process can be much efficient. Hydrogen can also be used for storing energy, transporting it and also for generating energy. However, effective technologies to do so on the large scales are yet to prosper.

## 3. PROMOTION OF GREEN CHEMISTRY

The principles of Green Chemistry solely focus on environment conservation and minimization of the various hazardous caused to the environment and the human health. Realizing this, efforts have been made to promote Green Chemistry. In the last decade, various organizations and institutions have been established in countries like Sweden, China, Taiwan, Australia (Centre for Greene Chemistry), Japan (Green and Sustainable Chemistry Network), Italy, Spain, Canada (Canadian Green Chemistry Network), Greece (Hellenic Network of Green Chemistry). American Chemical Society as well as the Royal Society of Chemistry have collaborated along with the educational sector with the goal of improvising the materials as well as programs intended for the students of Green Chemistry. [5, 23, 24] Moreover, German and Japanese Chemical Societies have taken the responsibility to promote Green Chemistry education in their respective countries- which is a remarkable attempt to promote this subject. In addition, Green Chemistry has been involved in the curriculum and courses on Green Chemistry and Green Engineering are available on various Universities across the World like "Industrial and Applied Green Chemistry, University of York, England", "Centre for Green Chemistry and Green Engineering, Yale University". Recently "Tribhuvan University" has incorporated "Green-Chemistry" in Bachelor 4$^{th}$ year. Moreover, many pharmaceutical as well as chemical companies have actively participated in promotion and development of Green Chemistry by encouraging researches related to the field. Even awards related to Green Chemistry have been established in various developed countries. For example, Royal Australian Chemical Institute (RACI) has been giving awards to honor the researches and educational projects in Green Chemistry. Moreover, Interuniversity Consortium Chemistry for the Environment (INCA) honors three industries every year to the industries that effectively apply the Principles of Green Chemistry. Awards like "Greener Synthetic Pathways Award", "Greener Reaction Conditions Award", are given to inspire innovative projects and new discoveries related to green chemistry. In this way, not only the researchers but also the industrial-estate holders are inspired by various awards to apply the Principles of Green



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Chemistry. Moreover, journals like "Journal of Clean Processes and Products", "Green Chemistry for Sustainability", "The Green and Sustainable Chemistry", "Journal of Green Engineering", "Green Chemistry" publish various scientific articles related to Green Chemistry to provide access to various ideas related to the field and also to inspire the researchers to discover innovative ideas to promote the field of Green Chemistry.[2]

## 4. CONCLUSION

In this way, Green Chemistry governs not only environmental conservation but also economic progress and social prosperity by the effective means of reduction of wastes, increase in efficiency of energy sources, promotion of renewable sources of energy, proper design of less hazardous products and reduction of the risks involved during synthetic processes. Efforts have thus been made to promote this aspect of Science by means of awarding the researchers who make significant contribution to the field, providing opportunities for students to study this subject, inspiring them to get involved in research work, and motivating the industrial owners to practise Green Chemistry in their production procedures. If this continues, miraculous results are expected to come from the efforts of Green Chemists and the proper implementation of the principles of Green Chemistry within couple of decades.

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